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Distributed Mode Filtering Rod Fiber Amplifier With Improved Mode Stability

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Abstract: We report 216W of average output power from a photonic crystal rod fiber amplifier. We demonstrate 44% power improvement before onset of the mode instability by operating the rod fiber in a leaky guiding regime.

OCIS codes: (060.2320) Fiber optics amplifiers and oscillators; (060.4005) Micro structured fibers.

Introduction

During the last years, photonic crystal based fiber lasers and amplifiers have undergone a massive improvement both with respect to beam quality performance and high average and peak power using fibers having very large mode area [1,2]. However, large effective area fibers often support increasing number of higher order modes and new methods to suppress them have been demonstrated [3,4]. Recent, experimental studies have shown a significant beam quality degradation of the fiber lasers and amplifiers when operating at high average power levels [5-7]. High average power levels can cause severe mode instabilities, occurring at some threshold level, and the level seems mostly depend on the effective area and inversion profile [6].

The causes of the mode instabilities are still under discussion. But recent development has pushed the level for mode instabilities by using rod fibers having a central doped core providing some degree of preferential gain for the fundamental mode, on the cost of reduced pump absorption [8]. In this paper, we demonstrate performance of photonic crystal bandgap rod fiber design [3] having precisely tuned Distributed-Mode-Filtering (DMF) elements. The same rod fiber design was used in a q-switched laser configuration with high efficiency and good beam quality, without indication of mode instabilities [9]. However, in those experiments the output power was limited by the pump power and the mode instability threshold level was not reached. We report the performance of the same rod fiber design in an amplifier configuration, this time with sufficient pump power available reaching the mode instability threshold level. We will further demonstrate a rod fiber design with an improved mode instability threshold level from 150W to 216W, when the DMF rod fiber is operated in a leaky guiding regime.

Experiments

The DMF rod fibers, demonstrated in [3], have different guiding regimes and are designed to work in a specific wavelength ranges. Fig. 1(a) shows a transmission measurement of a passive DMF rod fiber, having a mode field diameter of 60μm, and measured Near-Field (NF) images at two different guiding regimes, one at the leaky region (1030nm) and one at the single mode region (1060nm). Therefore, this DMF rod fiber has optimized operation at 1060nm, rather than at 1030nm.

In our experiments, we use a polarized seed source delivering ~30ps pulses at ~1032nm with 40MHz repetition rate, having 0.25nm spectral width and max average output power of 1.7W. The DMF rod fibers are pumped in counter-propagating direction with a pump module delivering up to 600W of pump power (976nm, 400μm, 0.22NA). We single-pass both the pump and the signal and use a CCD camera, at the output side, to verify the quality of the output beam (frame rate ~20-30Hz).

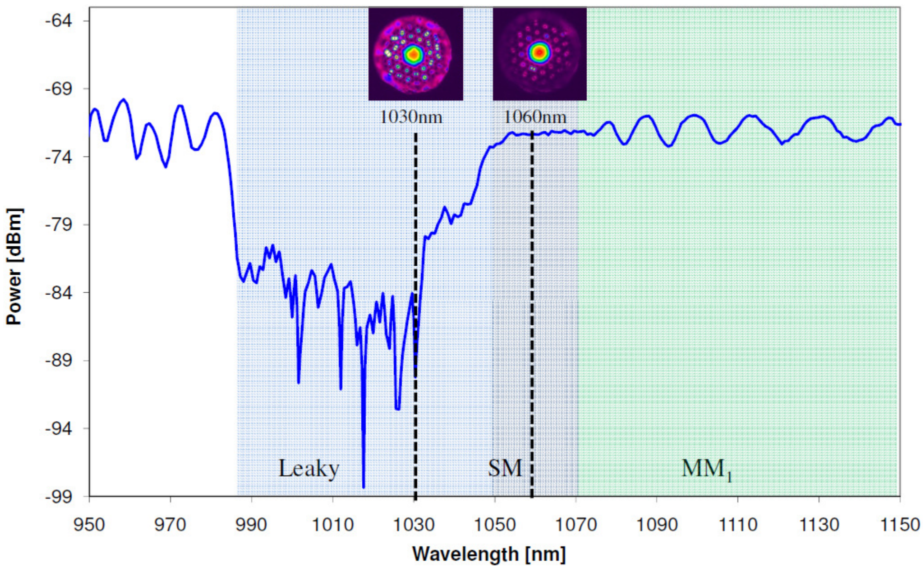

Fig. 1. (a) Transmission measured of a passive DMF rod fiber having a mode field diameter of 60µm. Interference patterns, in the spectrum indicate multimode behavior, a dip the leaky regime, and the single mode region can be identified between 1050nm – 1070nm. Measured near field images show the guiding dynamics of the DMF rod fiber.

We use two different ytterbium-doped double-clad DMF rod fibers in an amplifier configuration. The DMF rod fibers were manufactured to be single mode in two different wavelength regions, one at 1030-1045nm, referred to as "DMF1030" and the other 1050-1070nm, referred to as "DMF1064". The DMF rod fibers have a core diameter of ~85µm, having an estimated NA ~0.01 and a pump cladding of 267µm with ~0.6NA. The DMF rod fibers are 90cm long, having pump absorption of ~27dB/m at 976nm and both of the ends are prepared with AR-coated end caps.

Fig. 2 shows slope effiencies of both DMF rod fibers and the output spectra at the maximum output powers. The DMF1030 has a slope efficiency of 71% and a maximum available output power of 150W before the onset of the mode instability. The spectrum was recorded at 150W of output power with FWHM of ~0.3nm. The DMF1064 has a slope efficiency of 75% but the maximum available output power is much higher than for the DMF1030. The DMF1064 shows significant mode stability improvement and the onset of the mode instability is found at 216W. The recorded spectrum, in Fig. 2(b) at 216W of output power, has ~0.3nm of FWHM.

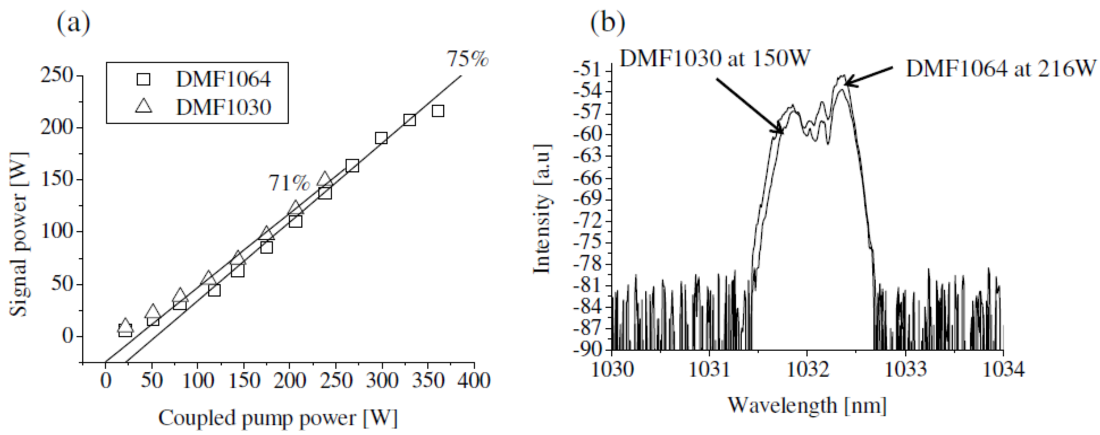

Fig. 2. (a) Slope efficiency measurement of the DMF1030 and the DMF1064. (b) Recorded output spectra at the maximum output powers.

When the DMF1064 is used with a 1030nm signal it operates in the leaky regime, where the fundamental mode is coupled to the DMF elements and has high confinement loss. At low output power levels (<50W), the core mode appears to be leaky with high amount of cladding light, but becomes more confined at higher output power levels

(>80W), as shown in Fig. 3(b). This can also be observed from the signal core to cladding ratio, shown in Fig. 3(a), which shows that the core light increases from 60% to 90% with increasing power. The increased confinement loss at low power levels also decreases slope efficiency at low power levels, as shown in Fig. 2(a).

This indicates that the confinement loss decreases with increasing output power levels. This could be caused by a thermally introduced refractive index change of the core. As the DMF1064 is operated in the leaky regime at low power levels and as the power is increased, the thermal load will raise the refractive index of the core and the DMF filtering effect is blue shifted. This can be seen from Fig. 1 as a blue shift of the transmission spectrum. This blue shift will provide better confinement for the fundamental mode.

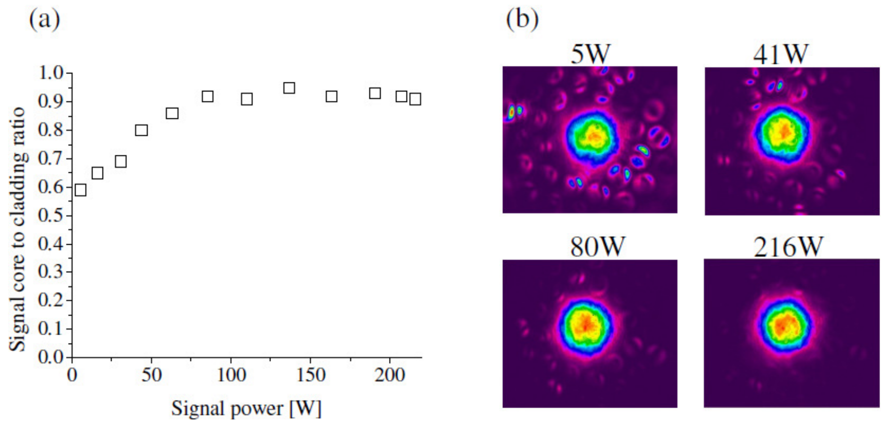

Fig. 3. (a) Measured signal core to cladding ratio of the DMF1064. (b) Recorded evolution of NR image quality at different signal output powers (DMF1064).

Conclusions

We have demonstrated a high power fiber amplifier utilizing the Distributed-Mode-Filtering (DMF) rod fiber design having improved mode stability up to 216W of average output power. We reported a mode instability threshold output power level improvement of 44% by operating the DMF rod fiber in the leaky regime. We speculate that the change of the guiding regimes is caused by a thermally introduced refractive index change of the core. We observe the change in the confinement by measuring the signal core to cladding ratio and near fields at different output power levels.

Acknowledgements

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